

A 30-Day Forecast Experiment with the GISS

Model and Updated Sea Surface Temperatures<sup>1,2</sup>

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## Introduction

Coupled ocean-atmosphere models are under active development at many of the laboratories devoted to general circulation research. The primary objective of these efforts at the present time is atmospheric climate simulation without the constraint of sea surface temperature (SST) specification, as well as ocean "climate" simulation without the imposition of specified atmospheric properties. However, a possible future benefit of coupled general circulation models may well be in the area of dynamical long-range weather prediction.

The expectation that long-range weather forecasting might be advanced through the use of coupled models is based on the role of the active upper layer of the ocean as a thermal energy source for the atmosphere. One of the many causes of forecast error in numerical weather prediction models is incorrect SST specification. Regardless of whether climatological or observed SST values are used for the calculation of surface fluxes over the ocean, the SST field will eventually be in error, unless it can be accurately predicted. A successful coupled model may mitigate this problem. However, there are various reasons why a coupled model may fail to extend the useful range of predictability. The inherent predictability limits of a coupled model may be even worse than those of an atmospheric model. The SST prediction errors in an imperfect coupled model may introduce "noise" in the atmospheric forecast. And, even if a perfect SST forecast is made, the influence of SST variations over the forecast period may be negligible compared with other causes of decay of predictability.

Some insight into the possibility of extending the useful range of atmospheric predictions through coupled models may be gained through experiments with an atmospheric model in which the SST field, while prescribed, is altered during the forecast run to correspond to the observed SST field. In such an experiment, the atmospheric forecast is computed almost as it would be with a coupled model in which the ocean prediction provides a perfect SST forecast for the atmospheric calculations, with the feedback simulated through the use of observed SST's.

A prediction experiment of this kind was carried out with the nine-level global general circulation model developed at the Goddard Institute for Space Studies (GISS). The so-called GISS model, which has been described by Somerville, et al. (1974), is derived from the models of A. Arakawa and Y. Mintz (see, e.g., Arakawa, 1972), but employs greater vertical resolution and a somewhat different treatment of moist convection, turbulent sub-grid processes, and solar and terrestrial radiation. While designed as a general circulation model, the GISS model is also believed to be representative of the current "state of the art" of numerical weather prediction (Druyan, 1974).

In the GISS SST update experiment, forecasts were computed, in 5-minute time steps, for a period of one month from initial data for OOGMT, 1 January 1974. The forecasts were printed at 12 hour intervals, and forecasts of mean conditions for the whole month were also computed. Two pairs of predictions were generated. In one, referred to as the C ("Climatology" or "Control") run, the climatological January mean SST field (from Washington and Thiel, 1970) was used for the total period, while in the other, referred to as the A ("Anomaly" or "Actual") run, the specified SST values were updated for each day of the forecast using the appropriate "observed" values at each gridpoint.

The effect on forecast quality of updating the SST fields, rather than using climatological mean SST values for the surface flux calculations, was evaluated through comparisons of the growth of daily root-mean-square (rms) errors, the rms errors and gradient skill scores of the predicted monthly mean fields, and the prognostic monthly mean synoptic maps themselves. The general conclusion from the experiment is that, in the case studied, updating the sea surface temperatures did not lead to any detectable unambiguous improvement in forecast quality over a period of one month. However, this result should be viewed cautiously in view of the fact that the SST anomaly field in January 1974 was a relatively modest one in terms of scale, magnitude, and persistence, and the SST data are of dubious quality.

### Data

The global atmospheric data set for the month of January 1974 was provided by the National Meteorological Center (NMC). The "data" are derived from a spectral analysis in which spherical Hough functions are fitted to the global observations (Flattery, 1970; National Weather Service, 1974). The NMC data were interpolated into the GISS coordinate system, and used in that form for both the initial conditions and the verifications of the forecast runs. (The GISS model uses a spherical mesh of 4 degrees of latitude by 5 degrees of longitude.)

Two sets of daily SST fields were used in the experiment. One set, obtained from the U.S. Navy Fleet Numerical Weather Central (FNWC), is derived from surface ship and buoy observations, supplemented by satellite data, and is available only for the Northern Hemisphere. The second set, derived from window channel infrared radiances monitored by meteorological satellite scanning radiometers, is available for the whole earth and was furnished by the National Environmental Satellite Service (NESS) of NOAA.<sup>4</sup> The two SST analyses are not entirely independent, as both use some surface and satellite data, as well as climatological information, in the data processing. Nevertheless, the fields differ somewhat, and, as they complement each other geographically, both were used to derive a single global SST field for each day of the month.

The two fields were combined by a method designed to maximize the observed SST anomaly, i.e., the deviation from climatology, which in this case is the mean January SST (from Washington and Thiel, 1970).

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At the same time, excessive anomalies were viewed as being probably erroneous. In the Southern Hemisphere, NESS values were used exclusively. In the Northern Hemisphere, where both FNWC and NESS values were available, the value corresponding to the greater absolute anomaly was accepted. However, in both hemispheres, if the NESS value indicated an absolute anomaly in excess of  $6^{\circ}\text{C}$ , it was discarded. If neither the FNWC nor NESS value was available at a gridpoint, the January SST climatology was used.

In view of the well-known errors in sea surface temperature measurements by ships (Saur, 1963), as well as the errors in SST's deduced from clear sky infrared radiances (Smith, et al., 1974; Wark, et al., 1974), it is probably not unreasonable to assign an uncertainty of  $\pm 1^{\circ}\text{C}$  to both sets of values. Thus, daily SST anomalies smaller than  $\pm 1^{\circ}\text{C}$  are almost certainly in the field noise and should be ignored. However, even larger anomalies are not necessarily reliable, particularly if they are of short duration and small scale. On the other hand, there are some persistent and larger scale features of the SST anomaly field which are more credible. These can be seen most clearly in the monthly mean SST anomaly fields for January 1974.

Three mean January 1974 SST anomaly maps are shown in figures 1, 2, and 3. Figure 1 represents the global SST anomaly pattern based only on the "NESS" satellite data. Figure 2 shows the SST anomaly pattern in the Northern Hemisphere derived from the FNWC data, and figure 3 illustrates the SST anomaly field resulting from the combination of NESS and FNWC data, which were used in the present experiment.

In the Southern Hemisphere, where only NESS data (fig. 1) were used, the SST anomaly field exhibits a banded zonal structure, with cold anomalies at low and high latitudes and warm anomalies in middle latitudes. The largest, and geographically most coherent

SST anomalies are found in the South Pacific Ocean. The NESS SST anomaly field in the Northern Hemisphere (fig. 1) shows a similar general pattern of positive anomalies in middle latitudes, with negative anomalies in high and low latitudes, although it is not as well organized as in the Southern Hemisphere. The largest and most coherent warm anomalies in the Northern Hemisphere are found in the western Pacific, according to the NESS data (fig. 1).

The mean January 1974 FNWC SST anomaly field (fig. 2) is seen to be rather different from the NESS field in the Northern Hemisphere. Major differences between the two are found in high latitudes in both the Atlantic and Pacific Oceans, and off the east coast of North America. Near the Aleutian Islands in the Pacific, and adjacent to the east coast of the United States, the FNWC field indicates warmer water than does the NESS field, while between Newfoundland and Greenland and north of Iceland the FNWC data show much colder water. Differences are also found off the west African coast, south of Iceland, in the mid-Atlantic, in the Gulf of Alaska, and in the sub-tropical Pacific. On the other hand, the principal warm SST anomalies on the western sides of the Atlantic and Pacific Oceans do appear on both maps.

The composite SST anomaly field (fig. 3), resulting from the blending of the daily NESS and FNWC data for January 1974, is essentially the same as the NESS field in the Southern Hemisphere. In the Northern Hemisphere, on the other hand, the warm anomalies on the western sides of the oceans are (as might be expected from the blending method) larger both in magnitude and geographical extent on the composite map (fig. 3) than on the NESS map (fig. 1). Thus, the composite SST anomalies, especially in the Pacific, exhibit even more clearly the zonal pattern of colder than normal sea temperatures in the equatorial region, and warmer

than normal sea temperatures in middle latitudes of both hemispheres. A possible atmospheric consequence of this pattern of SST anomalies would be a weakening of both the direct, thermally-driven Hadley circulation itself and the meridional transports by the tropical mean circulation (Bjerknes, 1966). (As shown below, the model does indeed generate such a response, but this does not appear to contribute to an improved forecast.)

We have also compared the daily maps of SST anomalies for January 1974 as derived from the NESS and FNWC data, and have noted some marked differences in the Northern Hemisphere. For example, the largest and most persistent warm anomalies in the NESS fields are found in the western Atlantic and Pacific Oceans, i.e., off the east coasts of North America and Asia, and also in the Central Pacific. However, the east coastal anomalies, in the FNWC fields are considerably smaller, weaker, and less persistent than those found in the NESS data, while in the central Pacific the warm anomaly is larger and stronger in the FNWC data.

None of the anomalies persists for the full month without change; all parts of the anomaly field, whether in NESS or FNWC data, exhibit marked fluctuations during the month in both hemispheres. In the Southern Hemisphere, the anomaly field is initially irregular, small scale, and weak, then grows into a well-organized, broad-scale system towards the end of the month. In the Northern Hemisphere, on the other hand, initially strong positive anomalies in the western Atlantic and in the western and central Pacific weaken during the month. Thus, the mean fields shown in figures 1, 2, and 3 do not represent constant features of the sea surface temperature field during January 1974.

The most consistent feature of the January 1974 SST anomaly field, one which is found almost every day in some form in both the FNWC and NESS data, is the anomalous warm water off the east coast of Asia.

One must, at this time, view the SST fields, particularly the daily patterns, with some skepticism. Both the observational methods and the techniques of analysis are imperfect, and there are undoubtedly real fluctuations in ocean temperatures on all scales which may or may not be represented in the coarse mesh data. It should also be noted that the month selected for this experiment was not one characterized by dramatically large and persistent SST anomalies, such as, for example, the 1968 anomaly studied by Namias (1971). Thus, we should be careful not to draw too general or sweeping conclusions regarding atmospheric response to sea temperature variations from this one experiment.

### Comparison of Forecasts

As expected, the daily forecast skill of the model degrades rapidly with time regardless of the SST field used. Figure 4 illustrates the rms forecast errors in the sea level pressures over a region of the eastern Pacific Ocean and North America between latitudes 30N-54N and longitudes 75W-180 at 12-hour intervals for a period of a month. During the first week the forecast degradation is virtually the same for both the C and A runs. For the first 16 days, the SST update run (A) does show an almost consistently smaller rms error than the C forecast, with a maximum difference of more than 2 mb (14 percent of the rms error) on day 14. However, for the next 9 days the C run exhibits a smaller rms error than the A run, with a maximum difference of more than 2 mb (20 percent of the rms error) on day 19. In any event, neither of the daily forecast sea level pressure fields appears to exhibit useful predictive skill beyond about the 4-th day, and any differences between the C and A runs are apparently no larger than differences that might result from random errors in the initial conditions (Spar and Atlas, 1974). The forecast comparison is, indeed, consistent with that reported by Spar and Atlas (1974) for an earlier extended forecast experiment from which it was concluded that the use of observed SST values did not yield any detectable improvements in the quality of the daily large scale prognostic maps.

The monthly mean sea level pressure fields for January 1974 forecast by both the C and A runs also suffer from some serious

defects<sup>5</sup>, as shown in figure 5. Although the forecast and observed mean sea level pressure patterns, illustrated in figure 5, are available for the whole earth, we will compare only the fields in the Northern Hemisphere, in view of the uncertainties of the Southern Hemisphere analyses. In the North Atlantic, both the predicted Azores - Bermuda high and Icelandic low are too weak compared with the observed systems. Hence, the predicted pressure gradients in the North Atlantic are also much weaker than observed. In the North Pacific, the forecast Aleutian low is not only weaker than observed, but is displaced too far to the east, so that again the predicted pressure gradient in the western Pacific is much weaker than observed, and the pressure field is, in fact, quite unrealistic.

Comparing the A and C forecasts, one finds only a relatively small, and indeed negative, influence of the SST variation on the predicted mean monthly pressure field. The Icelandic low and Azores - Bermuda high are both slightly weaker in the A than in the C forecast, and, hence, the predicted sea level pressure gradients in the North Atlantic are even more in error in A than in C. The deep cyclone in the western Pacific is not well predicted in the A computation, being displaced into the eastern Pacific, resulting in an even less satisfactory sea level pressure field than that forecast by C.

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<sup>5</sup> A second Control forecast has been run with an improved infrared radiation computation and a geographically variable continental albedo. The forecasts with this "corrected" model show some improvements over the original C model, e.g., a deeper and more realistic Icelandic low, as well as some greater deficiencies, e.g., a weaker and less realistic Asiatic high. However, for the purposes of this paper, which is concerned only with the impact of the SST field on a 30-day forecast, the original program is deemed to be adequate for the comparative analysis.

Another qualitative test of the impact of a variable SST field on forecast skill is the degree to which the deviation of the atmosphere from its climatological normal state is predicted. In particular, it is of interests to know how the major "centers of action" in the sea level pressure field in a given month depart from normal, and whether these departures are better predicted by a forecast computed with a variable SST field than on one based on climatological SST's. In Table 1 are listed the latitudes, longitudes and central pressures of the five major sea level pressure systems in the Northern Hemisphere. Tabulated are the normal January positions and pressures (from Crutcher and Meserve, 1970), the observed January 1974 values, the values predicted by the C and A runs, and, for comparison, the values for January 1973. Although they are of no particular statistical significance, the data shown in Table 1 do indicate the relative impact of the SST anomalies on the monthly mean forecast sea level pressures.

The Icelandic low was much deeper than normal in 1974, but close to its normal position. Both its location and the sign of its sea level pressure deviation from normal were, in fact, correctly predicted by the C forecast, although the depth of the Icelandic low was not. The A forecast, on the other hand, did not improve on the C forecast either in location or central pressure. The subtropical Atlantic high pressure belt was also close to its normal pressure and latitude in January 1974. While both the C and A computations indicated approximately the correct latitude for the system, neither forecast the pressure correctly, and, of the two, the A forecast was the poorer with regard to the deviation from normal. The continental anticyclone over Siberia in January 1974 was in a nearly normal state of development, but split into two centers. Both forecasts placed the high center

Table 1. Locations and central pressures of the major centers of action in the Northern Hemisphere.

| SYSTEM                    |          | NORMAL<br>JANUARY | OBSERVED<br>JANUARY 1974 | C-FORECAST | A-FORECAST | JANUARY 1973 |
|---------------------------|----------|-------------------|--------------------------|------------|------------|--------------|
| Icelandic<br>Low          | Lat.     | 60N               | 60N                      | 59N        | 55N        | 60N          |
|                           | Long.    | 30W               | 30W                      | 30W        | 30W        | 40W          |
|                           | Pressure | 996               | 974                      | 992        | 994        | 986          |
|                           | (mb)     |                   |                          |            |            |              |
| Azores<br>Bermuda<br>High | Lat.     | 25-35N            | 30N                      | 28N        | 28N        | 25-35N       |
|                           | Long.    | -                 | -                        | -          | -          | -            |
|                           | Pressure | 1024              | 1025                     | 1018       | 1016       | 1024         |
| Asiatic<br>High           | Lat.     | 50N               | 50N + 65N                | 45N        | 45N        | 45N          |
|                           | Long.    | 95E               | 95E                      | 120E       | 120E       | 110E         |
|                           | Pressure | 1034              | 1032                     | 1024       | 1024       | 1030         |
| Pacific<br>Low            | Lat.     | 50N               | 45N                      | 45N        | 40N        | 55N          |
|                           | Long.    | 165W + 170E       | 170E                     | 180        | 160W       | 145W + 170E  |
|                           | Pressure | 998               | 994                      | 1010       | 1010       | 1002         |
| East<br>Pacific<br>High   | Lat.     | 30N               | 30N                      | 30N        | 30N        | 28N          |
|                           | Long.    | 140W              | 130W                     | 130W       | 130W       | 130W         |
|                           | Pressure | 1022              | 1018                     | 1018       | 1018       | 1022         |

east of its observed (and normal) position, and both were equally in error in the central pressure. In the Pacific Ocean, the western lobe of the Aleutian low was dominant in January 1974, and slightly deeper than normal. Both forecasts failed to reflect this development, indicating a weaker than normal Aleutian low, displaced too far to the east, with the larger position error in the A forecast. The east Pacific high pressure cell on the other hand was equally well-predicted by both the C and A runs. In general, the model appears to produce a monthly mean forecast that is somewhat closer to climatology than to the observed mean state.

As a further test of the two forecasts, we have compared several monthly mean meridional profiles predicted by each with those observed. Figure 6 shows the January 1974 mean meridional profiles of zonal wind, averaged zonally and vertically over all nine levels of the model. The two forecast profiles are almost identical. Both correctly predict the latitudes of the maximum westerlies and the latitude band occupied by the equatorial easterlies, and both fail to indicate the stronger westerly maximum in the Southern Hemisphere. (The latter may, of course, be an artificial result of the analysis in a sparse data area.)

The meridional transports of zonal angular momentum by eddies and by the mean meridional circulation (vertically and zonally averaged) are shown in figure 7. The eddy transports in the model appear to be much larger in the Southern Hemisphere than observed. This may, however, be a result of fictitious smoothing in the Southern Hemisphere due to a lack of data. In the Northern Hemisphere, on the other hand, the model underestimates the maximum momentum transport by eddies, and in the A run the maximum eddy transport is even smaller than in the C forecast. The predicted momentum transports by the mean meridional circulation in the

Northern Hemisphere (fig. 7) are also in disagreement with the "observed" values. The "observed" positive maximum (representing poleward transport of zonal angular momentum) is about twice as large as the predicted maxima, and is located 14 degrees farther north. (The absence of any observed meridional transports of angular momentum by mean motions in the Southern Hemisphere again appears to be the result of data deficiencies and smoothing.) The predicted poleward transport of angular momentum by the Hadley circulation in the Northern Hemisphere is seen to be slightly weaker, and thus again even more in error, in the A than in the C forecast. As expected, the SST anomaly field, with relatively cold equatorial water and warm mid-latitude water, appears to weaken the predicted Hadley circulation. However, the effect of the reaction on the predicted meridional momentum transports, as well as on the predicted mean fields, is apparently not beneficial in this case. Both the eddy and mean meridional transports of zonal angular momentum disagree even more with the observed transports when updated SST values are used than when climatological SSTs are employed in the surface flux calculations.

This negative result is, however, not consistent throughout. In figure 8 are shown the mean monthly meridional transports of sensible heat for January 1974 by both eddies and mean motions, again averaged vertically and zonally. Here one can see that both the C and A forecasts are in fair agreement in the Northern Hemisphere with the observed values, except for the latitude shift of the Hadley transport. The model exhibits a southward heat transport across the Equator, with a maximum at 10N, while the data indicate zero heat transport across the Equator, with a maximum southward transport at 18N. However, in this case, the predicted heat transport by the Hadley circulation is closer to the observed

transport in the A rather than in the C forecast. The SST anomaly field results in a weaker heat transport due to a weakening of both the meridional temperature gradient and the Hadley circulation, and in this instance the effect is apparently beneficial.

One simple measure of forecast quality is the rms difference between the monthly mean forecast and observed fields. (See Druyan, 1974, for details of the verification computations.) Shown in Table 2 are the rms errors of four "forecasts" of the January 1974 mean sea level pressures, 500-mb heights, and 850-mb temperatures. The letters C and A again denote, respectively, the "Control" forecasts, computed using climatological January SST's, and the "Anomaly" forecasts, computed with the daily updated SST's. The letter M indicates a "climatology forecast" for January 1974, the rms "error" in this case representing the rms deviation of the observed January 1974 atmosphere from the climatological January mean. (Global monthly mean climatological data were provided on tapes by the National Center for Atmospheric Research.) A persistence forecast, designated P, which used as the "forecast" for the month the initial state of the atmosphere on 1 January 1974, was also evaluated against the observed mean January 1974 atmosphere.

The rms forecast errors are shown in Table 2 for seven areas: the globe; a tropical belt between latitudes 22N and 22S; the Northern Hemisphere; a region covering the eastern Pacific and the United States between latitudes 30N - 54N and longitudes 75W - 180°; a region including the United States between latitudes 30N - 54N and longitudes 75W - 130W; North American land points on the GISS grid between latitudes 30N - 70N and longitudes 75W - 130W; and European land points on the GISS grid between latitudes 34N - 86N and longitudes 10W - 40E. Minimum values are underlined.

(Spar, Atlas, and Kuo)

Table 2. Root-mean-square (rms) errors of forecast January 1974 mean sea level pressure (mb), 500-mb height (m), and 850-mb temperature ( $^{\circ}\text{C}$ ) fields. C and A denote the Control and Anomaly forecasts. M represents a "forecast" of climatology, and P is a persistence forecast. (See text for details.) The minimum value in each row is underlined.

|   | C           | A           | M           | P           |
|---|-------------|-------------|-------------|-------------|
| <u>Sea Level Pressure (millibars)</u>   |             |             |             |             |
| Globe (pole-to-pole)                    | <u>6.87</u> | 6.94        | 7.64        | 9.21        |
| Tropical Belt (22N-22S)                 | 3.57        | 3.63        | 3.24        | <u>1.91</u> |
| Northern Hemisphere                     | <u>7.33</u> | 7.42        | 9.15        | 11.7        |
| 30-54N and 75W-180 <sup>1</sup>         | <u>6.59</u> | 6.63        | 9.32        | 12.4        |
| "United States" (land): 30-54N; 75-130W | 5.52        | 4.60        | <u>3.37</u> | 9.51        |
| "North America" (land): 30-70N; 75-130W | 7.50        | 5.73        | <u>5.54</u> | 10.8        |
| "Europe" (land): 34-86N; 10W-40E        | 8.25        | <u>6.82</u> | 15.5        | 10.1        |
| <u>500-mb Height (meters)</u>           |             |             |             |             |
| Globe                                   | <u>68.5</u> | 74.3        | 87.5        | 93.3        |
| Tropical Belt                           | 38.9        | 39.9        | <u>24.8</u> | 29.3        |
| Northern Hemisphere                     | <u>75.6</u> | 82.5        | 108.        | 116.        |
| 30-54N and 75W-180 <sup>1</sup>         | 83.3        | <u>81.1</u> | 103.        | 114.        |
| "United States" (land): 30-54N; 75-130W | 99.7        | 90.9        | <u>79.8</u> | 101.        |
| "North America" (land): 30-70N; 75-130W | 89.8        | 84.8        | <u>82.8</u> | 151.        |
| "Europe" (land): 34-86N; 10W-40E        | 94.7        | <u>92.1</u> | 252.        | 121.        |
| <u>850-mb Temperature (degrees C)</u>   |             |             |             |             |
| Northern Hemisphere                     | <u>4.60</u> | 4.68        | 5.14        | 4.74        |
| 30-54N and 75W-180 <sup>1</sup>         | 5.60        | 5.06        | <u>3.26</u> | 6.30        |
| "United States": 30-54N; 75-130W        | 6.01        | 5.10        | 3.97        | 7.82        |

<sup>1</sup> A mid-latitude band in the Northern Hemisphere including the eastern Pacific and the United States.

With regard to the impact of SST updating on rms error, Table 2 is somewhat ambiguous. Over the large geographical regions (globe, tropical belt, and Northern Hemisphere) the C forecasts show smaller rms errors than do the A forecasts in all three prediction variables, indicating no beneficial impact of the SST updating. However, over smaller regions ("United States", "North America", "Europe"), the rms errors are smaller for the A forecasts, indicating some possible regional beneficial influence of SST updating.

Everywhere except in the tropical belt, the model forecasts are superior to persistence, in terms of rms errors. However, persistence clearly provides a better forecast of the monthly mean sea level pressure and 500-mb height fields in the tropical belt than does the model. Undoubtedly, tropical data deficiencies and the analysis techniques used in data sparse areas, as well as the actual persistence of January conditions in the tropics, all contribute to the relatively low rms errors of the persistence forecasts in the tropical belt.

Over both the globe and Northern Hemisphere, as well as "Europe", the model forecasts are, in an rms sense, superior to both climatology and persistence. However, over "North America", including the "United States", the model predictions for mean January 1974 exhibit larger rms errors than do the January climatology forecasts. The apparent ability of the model to improve on climatology over the Northern Hemisphere is, nevertheless, encouraging, despite its apparent failure in particular regions.

Another indicator of forecast skill is the S-1 skill score (Teweles and Wobus, 1954; see also Druryan, 1974), which is a dimensionless measure of the difference between predicted and observed horizontal gradients. As in the case of rms errors, lower skill scores signify better forecasts. Shown in Table 3 are the S-1 scores for sea level

(Spar, Atlas, and Kuo)

Table 3. S-1 skill scores (see Teweles and Wobus, 1954 and Druyan, 1974 for explanation) for forecasts of January 1974 mean sea level pressure and 500-mb height fields. (See Table 2 and text for further details.)

|                         | C           | A           | M    | P           |
|-------------------------|-------------|-------------|------|-------------|
| Sea Level Pressure      |             |             |      |             |
| Globe                   | <u>69.2</u> | 71.2        | 79.8 | 74.0        |
| Tropical Belt (22N-22S) | 69.2        | 69.8        | 80.1 | <u>60.4</u> |
| Northern Hemisphere     | <u>67.1</u> | 69.9        | 89.4 | 81.3        |
| "United States" (land)  | <u>93.3</u> | 98.5        | 101. | 96.7        |
| "North America" (land)  | <u>88.9</u> | 98.0        | 106. | 89.5        |
| "Europe" (land)         | 69.8        | <u>69.4</u> | 110. | 94.5        |
| 500-mb height           |             |             |      |             |
| Globe                   | <u>46.1</u> | 48.8        | 55.3 | 58.1        |
| Tropical Belt           | <u>65.2</u> | 68.7        | 71.9 | 69.3        |
| Northern Hemisphere     | <u>44.5</u> | 48.9        | 60.4 | 64.3        |
| "United States" (land)  | <u>23.3</u> | 30.4        | 41.0 | 52.1        |
| "North America" (land)  | <u>28.3</u> | 35.2        | 43.2 | 56.7        |
| "Europe" (land)         | <u>56.9</u> | 58.6        | 84.2 | 78.8        |

pressures and 500-mb heights for six regions: the globe; the tropical belt; the Northern Hemisphere; and land points only over the "United States", "North America", and "Europe", as previously defined. The letters C, A, M, and P, represent the four forecasts for mean January 1974, and have the same meaning as in Table 2. Minimum values are again underlined.

With only a minor exception (sea level pressure over Europe), Table 3 indicates that the C forecasts are superior to the A forecasts, indicating no clearly beneficial effect of SST updating on the model predictions. Also, with only one exception (sea level pressure in the tropics), the two model predictions are superior to both persistence and climatology, according to the S-1 scores. The latter result, together with the similar result in terms of rms error noted in Table 2, is rather encouraging, particularly with regard to the Northern Hemisphere, and suggests that the model may exhibit some useful skill in forecasting monthly mean fields, despite the decay of daily predictability.

### Conclusion

The one limited prediction experiment described in this paper indicates that updating sea surface temperatures did not result in any clear-cut improvement in forecast quality over a period of one month, either in the daily or monthly mean fields. Indeed, the impact of the SST anomalies on the prognoses was very slight. However, it must be acknowledged that the SST anomalies in the January 1974 case studied were relatively modest in scale, magnitude, and persistence, and undoubtedly are not representative of those large, persistent, and broad scale sea temperature anomalies which are occasionally found over the oceans. Further experimentation with real global data sets, including more reliable SST data, must be carried out before any final conclusions can be stated regarding the influence of sea temperature anomalies on extended and long-range dynamical prediction. It is desirable that such forecast experiments be performed with a variety of prediction and general circulation models.

A major limitation in any sensitivity test of the kind described above is the inherent decay of predictability of the model. It is doubtful that a very meaningful test of the impact of SST anomalies, or of any other influence, can be carried out for a forecast period in excess of a few days until the predictive skill of the models is substantially increased. However, despite the rapid decay of daily predictability of the GISS model ( and, indeed, of all models), it is encouraging to note that the model's forecasts of the monthly mean sea level pressure, 500 mb height, and 850 temperature fields over the Northern Hemisphere for January 1974 were superior to both climatology and persistence. Thus it appears worthwhile to continue both the efforts to improve the monthly mean forecasts and the experiments to test the impact of SST variations on the monthly predictions.

### Acknowledgements

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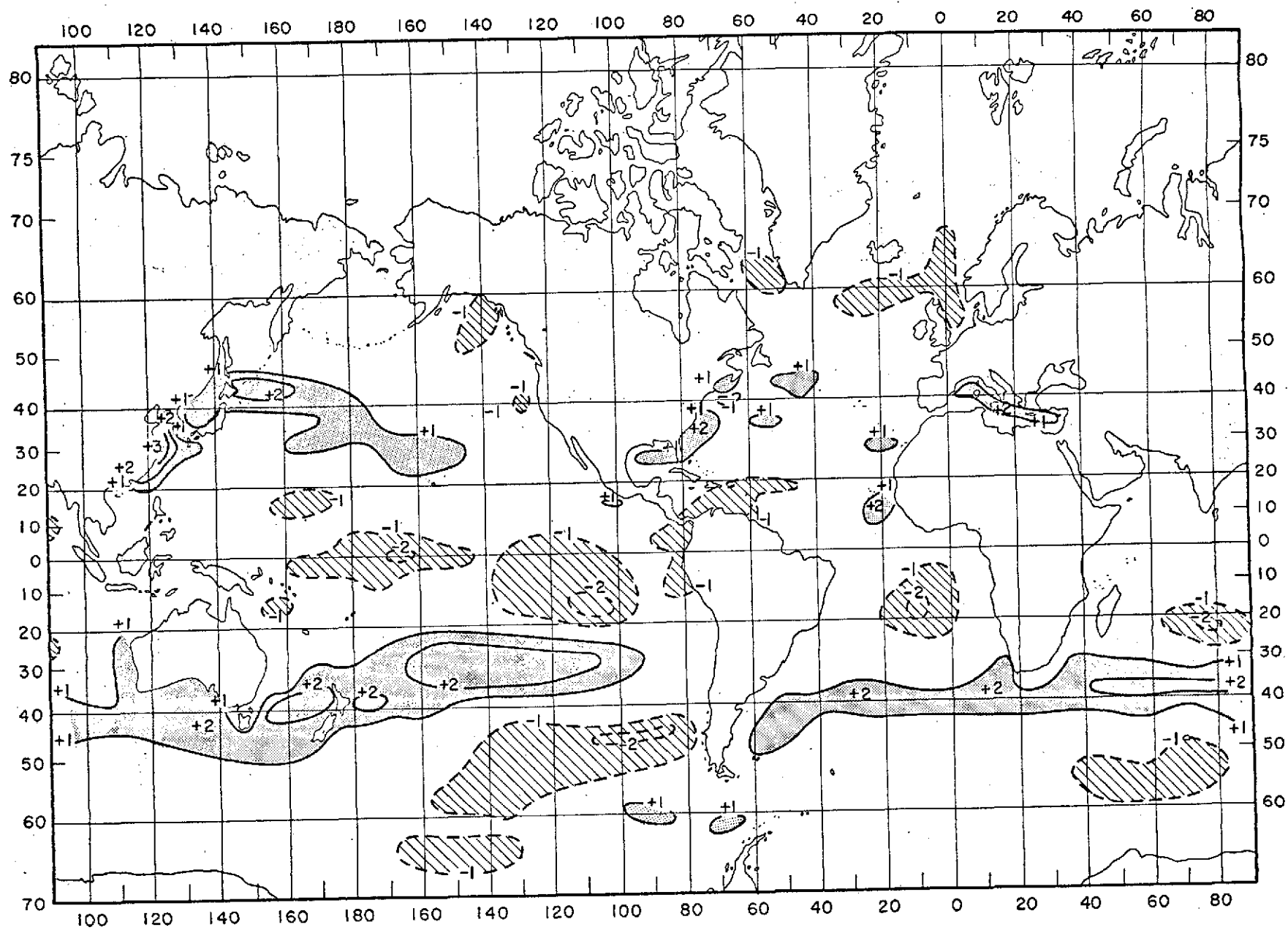
## Abstract

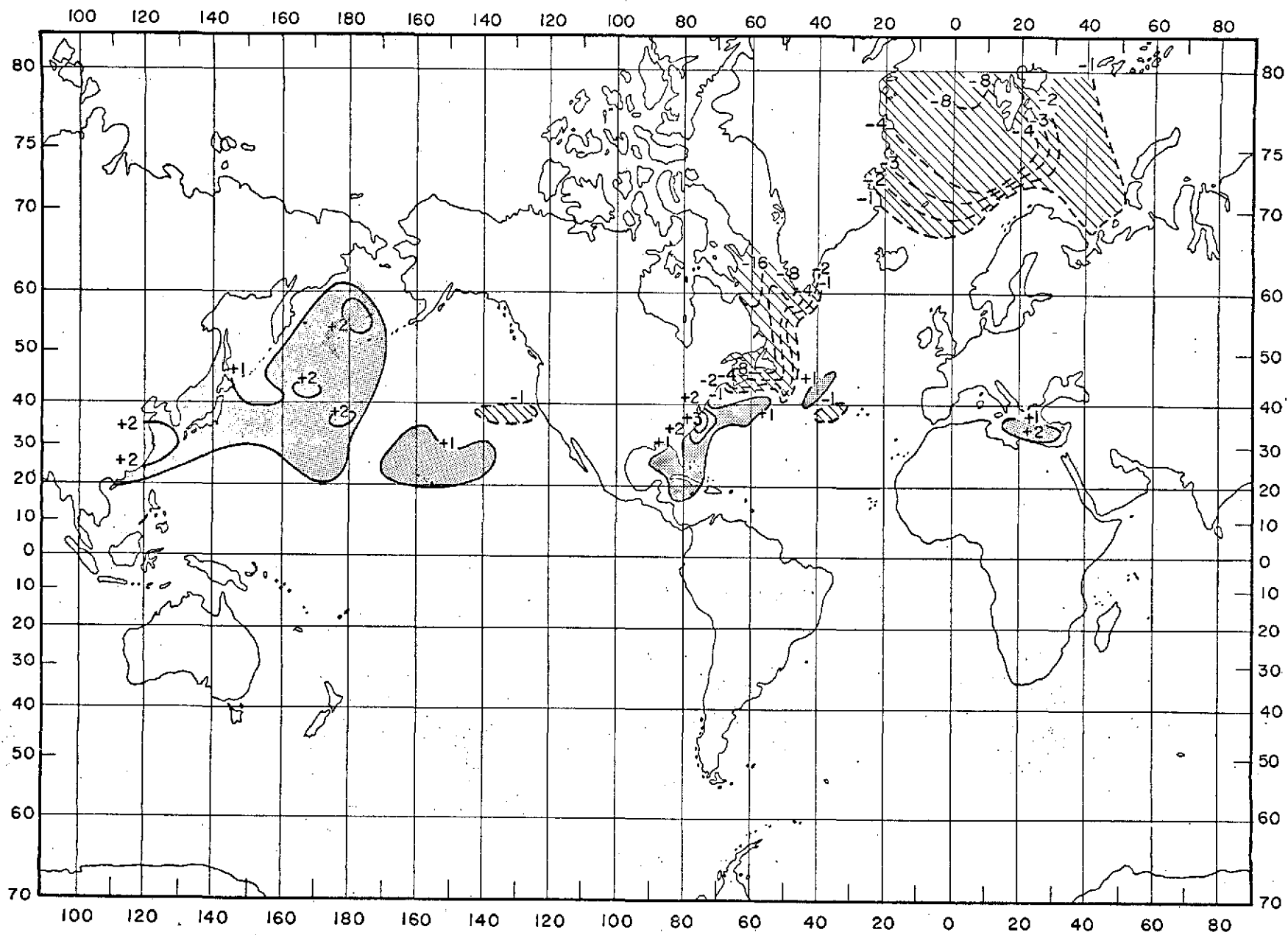
The GISS model has been used to compute two parallel global 30-day forecast for the month January 1974. In one forecast, climatological January sea surface temperatures were used, while in the other observed sea temperatures were inserted and updated daily. A comparison of the two forecasts indicated no clear-cut beneficial effect of daily updating of sea surface temperatures, and, in fact, only a slight impact of the updating on the forecasts. Despite the rapid decay of daily predictability, the model produced a 30-day mean forecast for January 1974 that was generally superior to persistence and climatology when evaluated over either the globe or the Northern Hemisphere, but not over smaller regions.

### Figures

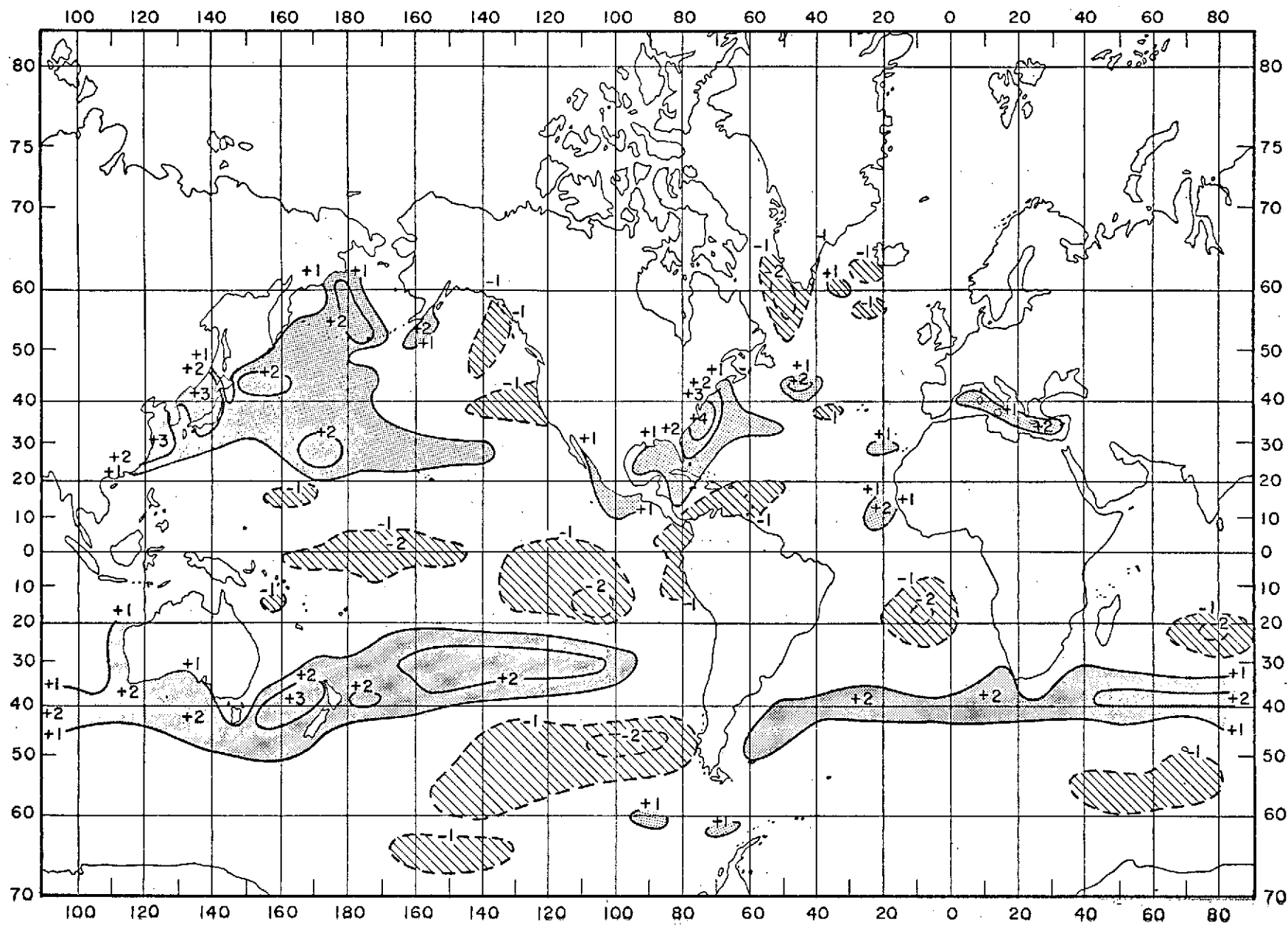
1. January 1974 sea surface temperature (SST) anomaly (degrees C) based only on satellite data provided by National Environmental Satellite Service (NESS), NOAA. (Anomaly is computed as the observed deviation relative to the January mean SST field from Washington and Thiel, 1970.)
2. January 1974 sea surface temperature (SST) anomaly (degrees C) in the Northern Hemisphere, based on data provided by U.S. Navy Fleet Numerical Weather Central, Monterey, California.
3. January 1974 sea surface temperature (SST) anomaly (degrees C) derived from merger of data in figures 1 and 2. (See text for details.)
4. Growth of root-mean-square (rms) errors of sea level pressure (mb) with time over the period January 1974. Errors, shown at 12-hour intervals, are for the region between latitudes 30N-50N and longitudes 75W-180. Dashed curve, C, represents forecast made with climatological sea surface temperature (SST) field. Solid curve, A, represents forecast made with daily updated SST field.
5. Mean January 1974 sea level pressure fields. C (top): predicted with climatological SST's. A (middle): predicted with daily up-dated SST's. O (bottom): observed.
6. Mean meridional profiles of zonal wind (meters sec<sup>-1</sup>) for January 1974 averaged zonally and vertically, with respect to pressure, over all nine levels of the GISS model. Top (C), middle (A), and bottom (O) figures show the Control, Anomaly, and Observed profiles, respectively.
7. Mean meridional profiles of meridional transports of zonal angular momentum ( $10^{30}$  gm cm<sup>2</sup> sec<sup>-1</sup> day<sup>-1</sup>) for January 1974 averaged zonally and vertically, as in fig. 6. Solid curves denote transports by mean meridional circulation and dashed curves represent transports by eddies. Top (C), middle (A), and bottom (O) figures show the Control, Anomaly, and Observed profiles respectively.

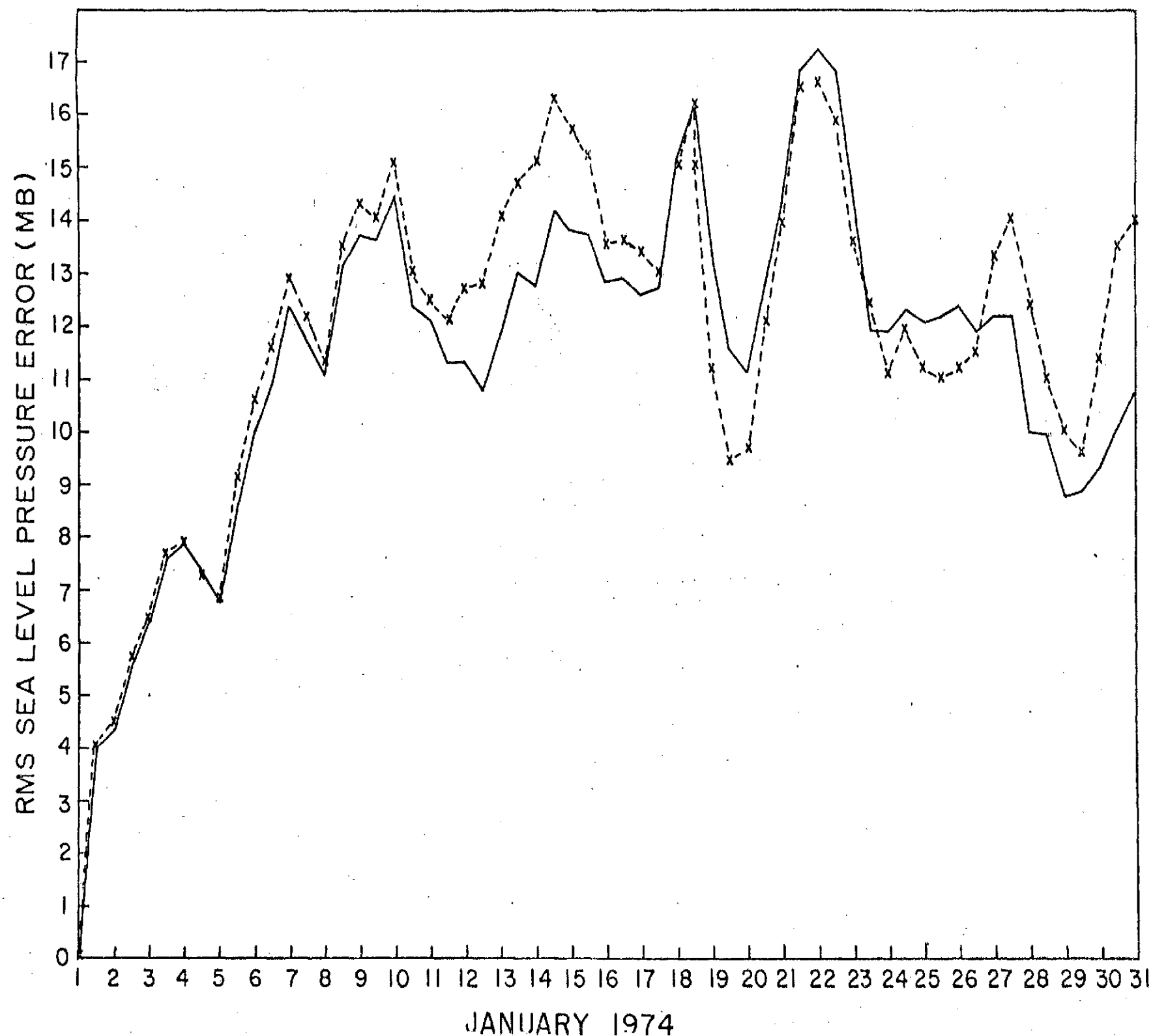
8. Mean meridional profiles of meridional transports of sensible heat ( $10^{19}$  cal day<sup>-1</sup>) in January 1974 averaged zonally and vertically, as in fig. 6. Solid curves denote transports by mean meridional circulation and dashed curves represent transports by eddies. Top (C), middle (A), and bottom (O) figures show the Control, Anomaly, and Observed profiles, respectively.



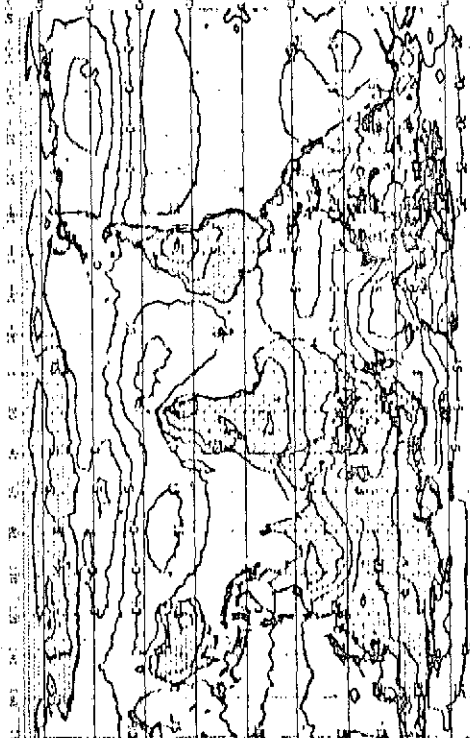
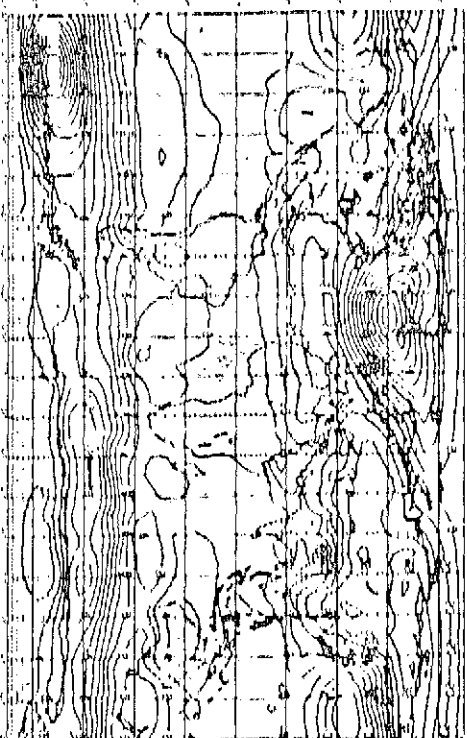


FNWC SST Anomaly, Jan '74 Span, et al. Fig





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